PLASMA-PROPELLANT INTERACTIONS

Interim Report No. 2
by

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December 2002

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13. ABSTRACT *(Maximum 200 Words)*

This is the second in a series of reports on our research on Propellant-Plasma Interactions. The first report described our facilities for testing propellants at high pressures. This report covers the design, fabrication and testing of equipment for producing and measuring controlled electric induced plasma discharges in the vicinity of explosive compositions. The next report will include Environmental Scanning Electron Microscopy (ESEM) micrographs of explosive surfaces that have been subjected to discharges.

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1. Introduction

The burning rate of the propellant is one of the main factors which affects the muzzle velocity of a projectile. In general, the burning rate of the propellant is dependent on the pressure of the system. Piobert's Law for propellant burning states that the rate is proportional to the pressure raised to a factor somewhere between 0.9 and 1.0. The temperature in the reaction zone is generally of the order of 2000-3000 K. Fine grained particles tend to burn faster than the larger grains. Overall, the burning rate can be affected by changing the pressure of the system, heating the reaction zone or altering the surface area open to combustion. One way in which these factors can be changed is by the addition of electrical energy.

Past research has studied the effect of thermal heating of the reaction zone using electrodes and passing electrical energy directly through the reaction zone. If the system is held at constant voltage the burning rate is increased but unstable. If, however, a constant current is passed the increase in burning is uniform. The effect can be assigned to resistive heating of the burning surface. While this increases the burning rate, the effect is limited by the increased electrical conductivity associated with higher temperatures. Therefore, at high initial temperatures it is more difficult to deposit high power into the system.

Another way of increasing the pressurisation rate is to introduce a hot gas or plasma into the burning zone. Increases in the burning rate and changes in the impulse history have been demonstrated in some systems. The addition of plasma allows a sharp pulse of energy to be delivered at any pressure. The disadvantage of this method is that there are several ways in which the plasma can interact, such as (i) the associated pressure pulse breaking up the surface of the propellant, (ii) a catalytic effect on the combustion process, (iii) heating of the combustion zone and/or electrical charging of the surface.

Understanding the nature of the combustion, propellant surface and plasma interaction is necessary to allow the burning rate to be controlled.

In this the first stage of the programme, the effect of the electrical discharge on the propellant system is outlined. A device has been constructed to deliver well-defined electrical energy to the system and has been calibrated. This device will be used to produce plasma by exploding a wire to form a plasma burst that will be directed at the burning surface. The effect of pure electrical discharge on a series of energetic materials is outlined.

This study will form the basis for the next stage in which plasma will be injected onto the propellant surface and the resulting damage analysed. Once the effect of (i) strong electrical fields and (ii) plasma on an unreacting surface are characterised this will allow their effect on a burning surface to be measured.

In recent experiments a variety of commonly used explosives and propellants were tested against different discharge energies. A preliminary assumption for the initiation of the energetic materials through an electrostatic discharge suggests that as the current is going through the material it creates hotspots of sufficient thermal energy to ignite them. An alternative mechanism for hot spot generation is that there are molten droplets in the plasma.

2. Equipment

- A capacitor bank with various options for the capacitance
- Charging control panel
- A discharge chamber
- Two oscilloscopes

The set up of the experiment is shown in figure 1 and Appendix A. The capacitor bank is connected to the Charging Control Panel which is used to select the energy stored in the capacitor bank. The voltage can be varied between 1-10kV and the capacitance in steps from the minimum of 892pF to a maximum of 87.622nF. The total energy delivered in the system is derived from the equation $(CV^2)/2$.

The capacitor bank is also connected to the discharge chamber where the behaviour of the energetic materials is studied. The discharge chamber is made of polycarbonate and is strong enough to survive any detonation or blast wave generated by the secondary explosive or propellant involved.

The capacitor bank is fitted with a voltage monitor and a Rigowsky coil. The out-puts go to two oscilloscopes. The first oscilloscope is set to measure the voltage and current histories on a long timescale of 20μs. The second oscilloscope measures these voltages at a shorter timescale of up to 10μs.

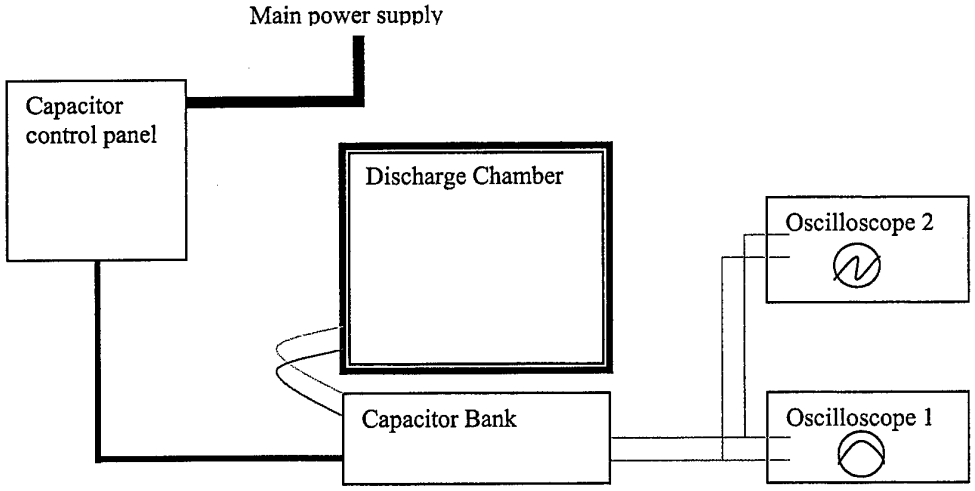


Figure 1, the set up of the experiment

3. Energetic materials

In the course of this research, the energetic materials that will be studied are,

- RF-38-13/2
- RF-69-01/9
- ROWANEX 1001/81
- ROWANEX 1400/41
- ROWANEX 3000/4

These are RDX/HTPB materials, though MG propellant samples will also be studied as well.

Samples of the energetic materials are placed in a holder that fits between the contact and the ground plate in the discharge chamber. The holder is a polymethylmethacrylate (PMMA) disc of 25mm diameter and 3mm thickness which has a hole drilled in its middle of 3mm diameter as shown in figure 2. The material that is to be tested is fitted into the hole. This set-up prevents the spark from making a shortcut other than through the material.

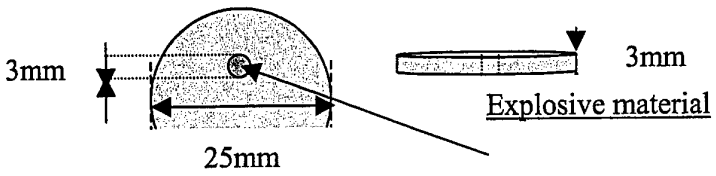


Figure 2. Holder for specimens in chamber

The volume of the energetic material that can be held in the hole is:
$\pi \times (1.5\times10^{-3})^2 \times 3\times10^{-3} \approx 21.2\times10^{-9}$ m^3

The mass of the sample can be determined once the density is known. The average mass of the samples was approximately 0.45 g.

4. Theory

The object of this experiment is to quantify the electrical input that can initiate the energetic material. The present theory for the initiation of the explosive assumes that as electrical current passes through the material it creates local hotspots on the material surface due to the rise in temperature along the path of the discharge. If there is enough thermal energy delivered to the surface, then the hotspots will ignite the system.

For examination of the explosive surface after a discharge, an Environmental Scanning Electron Microscopy (ESEM) is used. The main reason for this choice is that a conventional Scanning Electron Microscope (SEM) has to use high voltage very near the material surface with the associated risk of igniting the un-discharged surface and thus destroying the sample (and the microscope!). The main differences between SEM and ESEM are that there is no need for a high vacuum in the ESEM in the vicinity of the sample, charge on the specimen is removed by water vapour and other ions and consequently there is no need for coating or special treatment of the sample. The ESEM, however has a good vacuum near the electron gun. The electron beam then passes through a series of apertures which separate regions of increasing pressure.

ESEM is a variation of traditional SEM, and operates as follows.

A primary electron beam hits the specimen surface, which in turn emits secondary electrons. These secondary electrons are attracted to the positively charged detector electrode and as they travel through the gaseous environment, collisions occur

between electrons and gas particles, resulting in emission of more electrons and ionisation of the gas molecules. This increase in the number of electrons effectively amplifies the original secondary electron signal. The positively charged gas ions are attracted to the negatively biased specimen and offset charging effects. As the number of secondary electrons varies, the amplification effect of the gas varies. If a large number of electrons are emitted from a position on the specimen during a scan, there is a high signal. If only a small number of electrons are emitted the signal is less intense. The difference in signal intensity from different locations on the specimen allows an image to be formed. The gas itself can be altered to suit the sample under study, and may be, for example, water vapour, air, argon or nitrogen (Li et al., 1995).

All this means is that there is no need to coat the sample in order to make it electrically conducting. Also the ESEM works at relatively poor vacuum in the specimen chamber. This means that samples can be imaged in a gas or water vapour with good resolution (though poorer than SEM at present) with no dehydration. Magnifications up to 50,000 times - with resolution guaranteed to 10 nm - are possible. Specimens may be observed closer to their natural condition with no special preparation required (even for insulating samples), and X-ray analysis can be performed on non-conducting materials. Further information and micrographs of discharged surfaces will be given in the next report.

5. Results

Figures 3 & 4 give the voltage outputs measured during tests and calibration of the equipment.

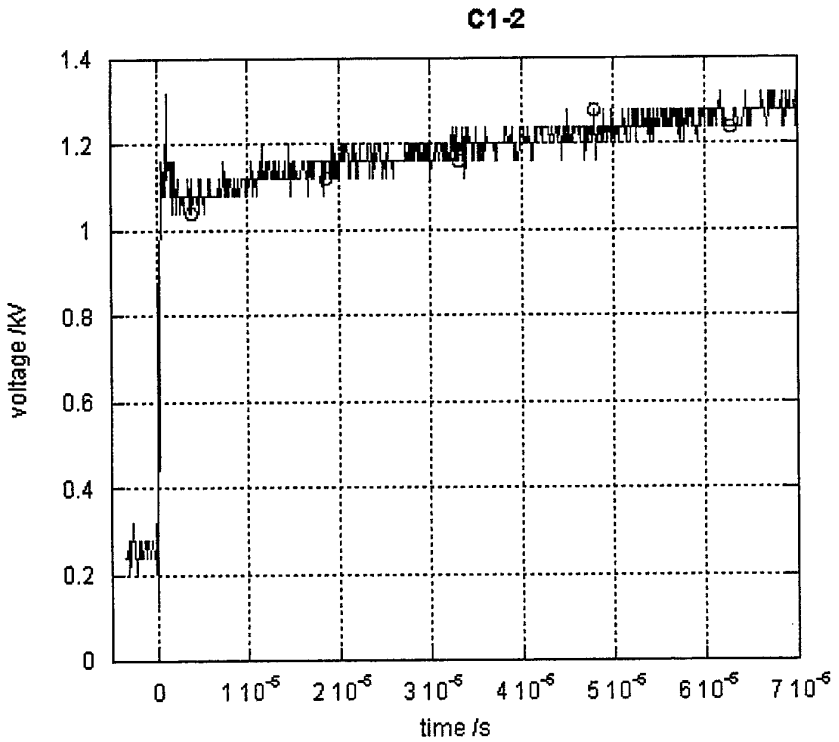


Figure 3: Trace C1-2 is for a low energy discharge in a material

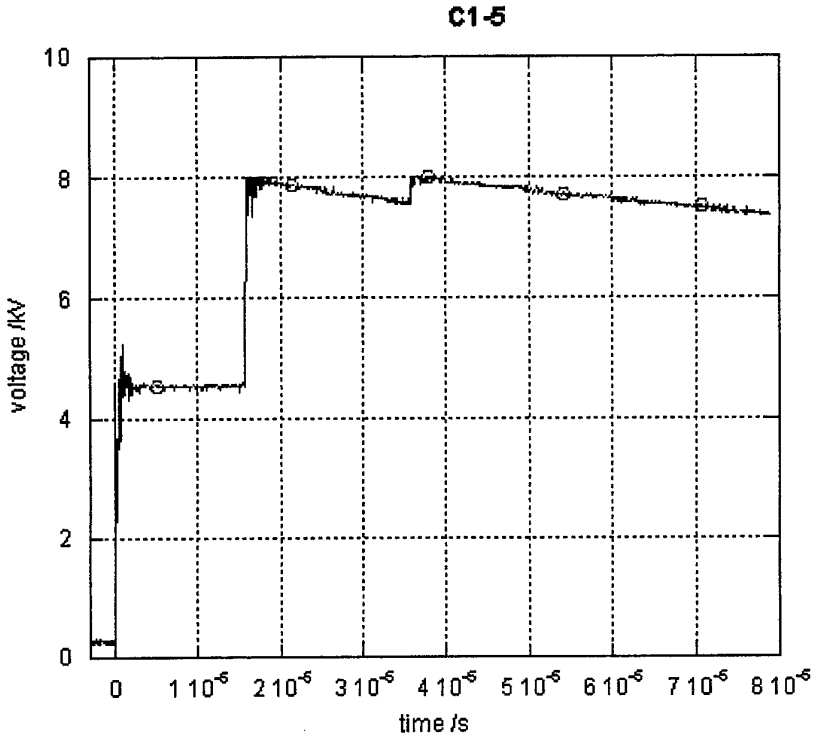


Figure 4: Trace C1-5 represents a higher energy discharge accompanied by physical damage to the target surface

In figures 5 and 6, the current output measurement is shown against time for the low energy and higher energy discharge of figures 3 & 4.

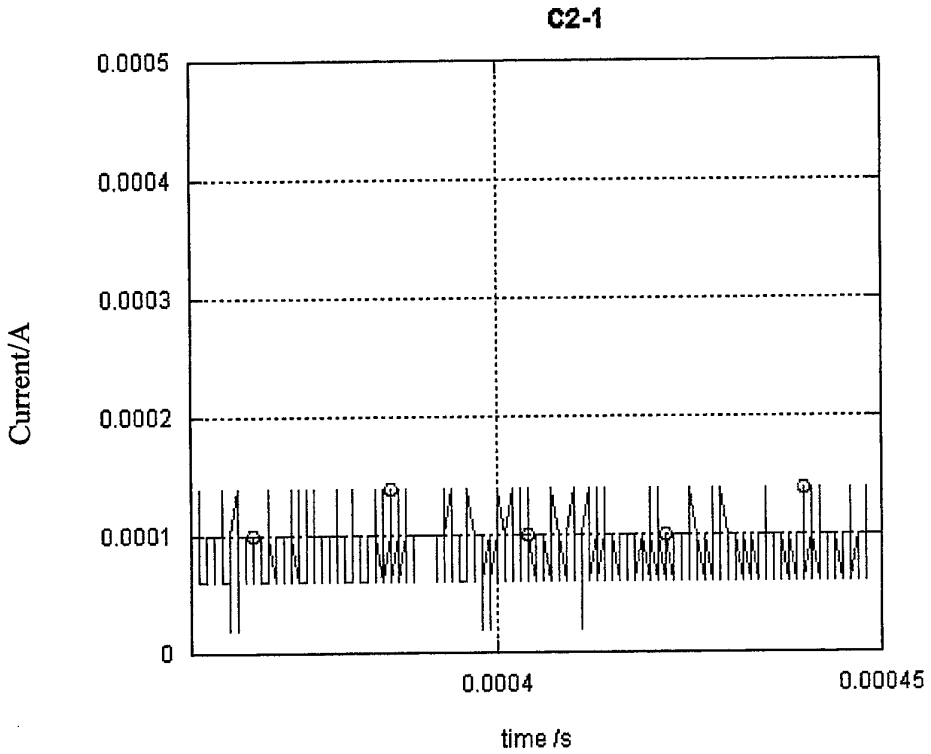


Figure 5: Trace C2-1 represents the low energy discharge with the current output measured

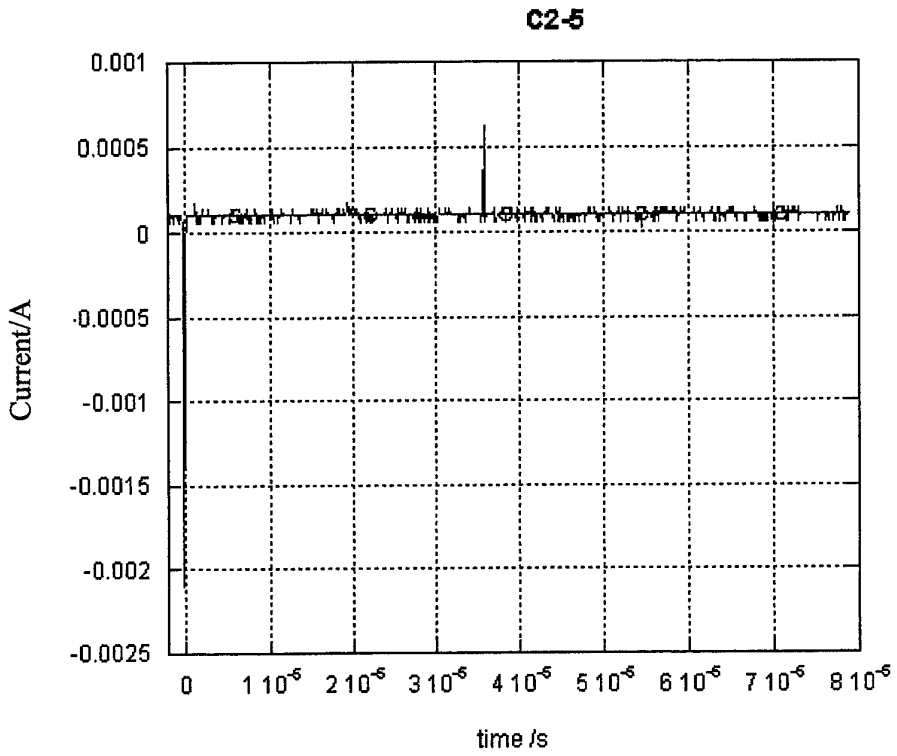


Figure 6: Trace C2-5 represents the higher energy discharge

In the low energy discharge the material was not physically altered at the point of contact. This can be seen as a build up of voltage across the material which was not been discharged. The current across the material was also observed to oscillate.

6. Future work

The experiments planned are divided into two parts. In the first, electro-static discharge (ESD) at a constant energy level near the sample will be studied. The only variation in the procedure of this part will be the materials used and the distance from the ESD will be varied. In order to produce the ESD, a tungsten wire will be vaporised to produce plasma.

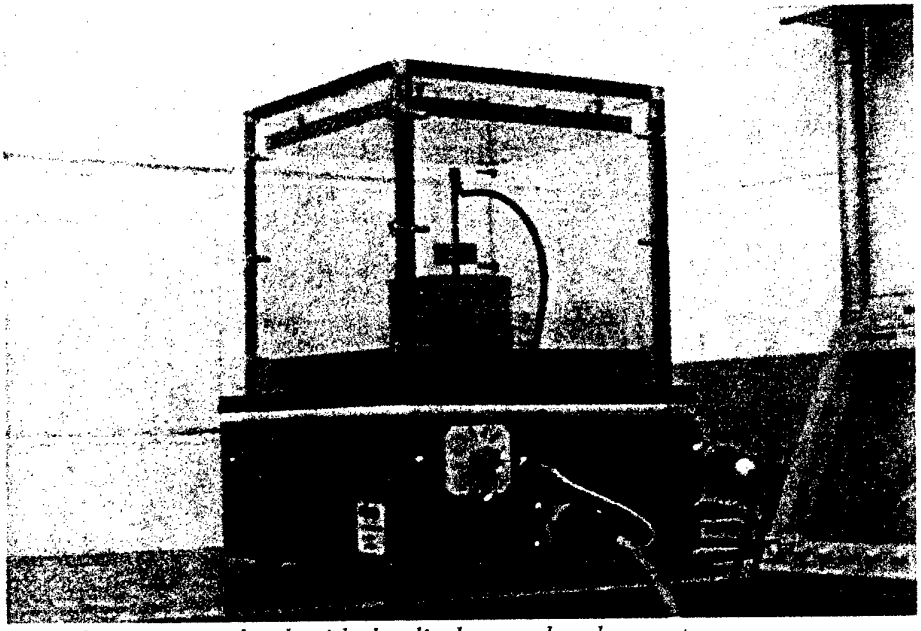
In the second part of the experiment, different energy levels of ESD will be applied at a set position from the sample.

There is a possibility that metallic particles contained in the plasma burst produce hot spots (Taylor 2002). We plan to investigate this mechanism.

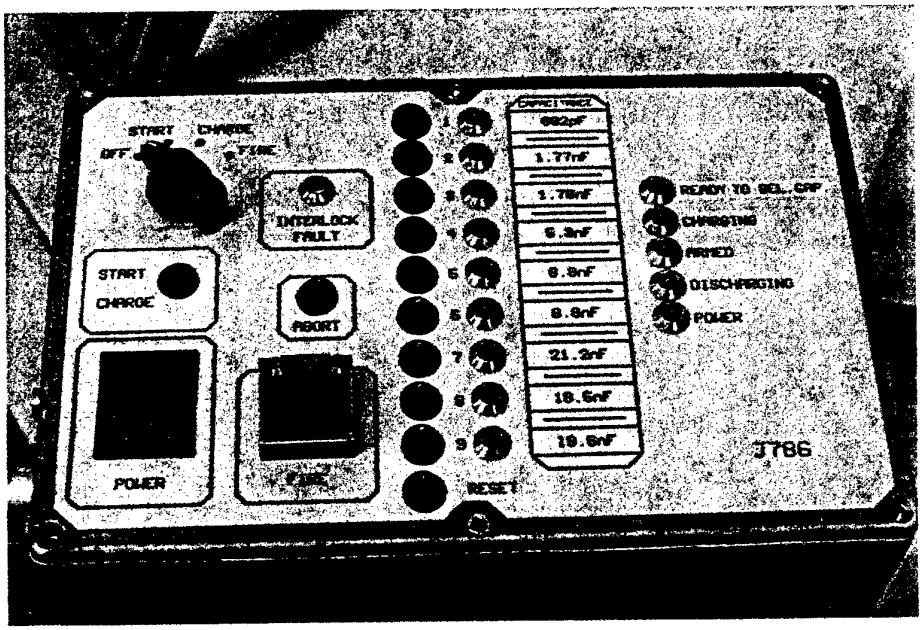
Reference

Taylor M. (2002 et al) PhD thesis, Cranfield University

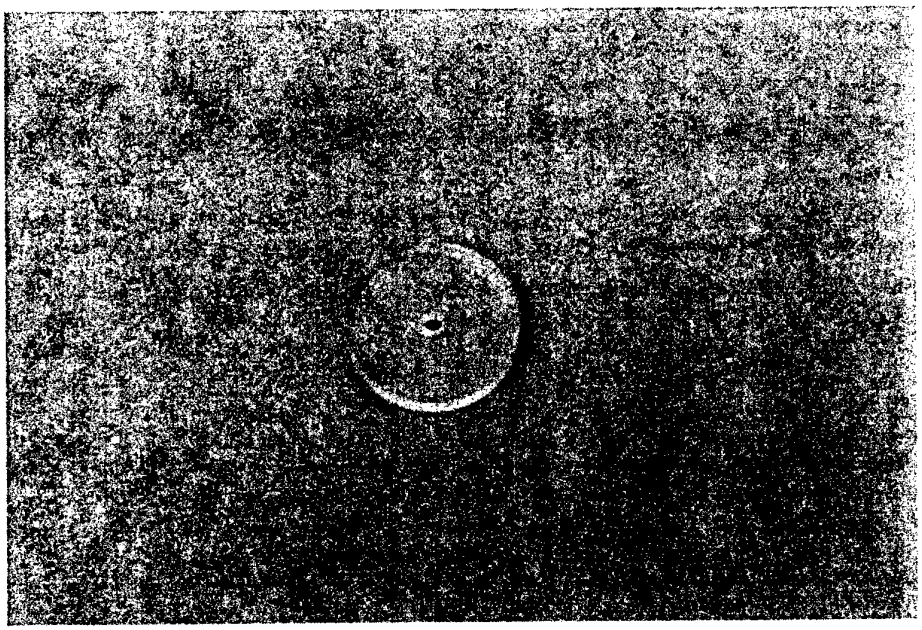
Appendix A



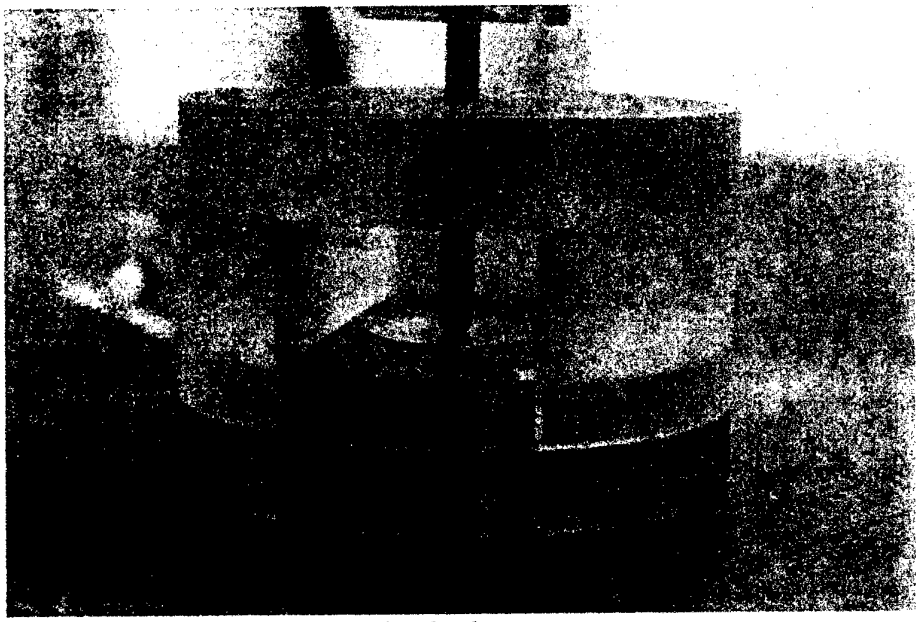
A 1. The capacitor bank with the discharge chamber on top



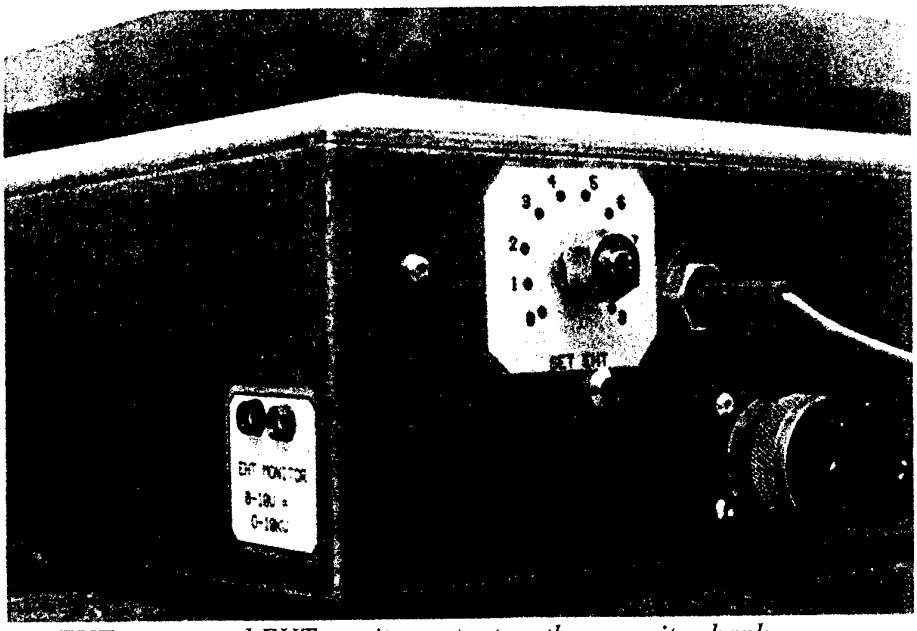
A 2. The control panel



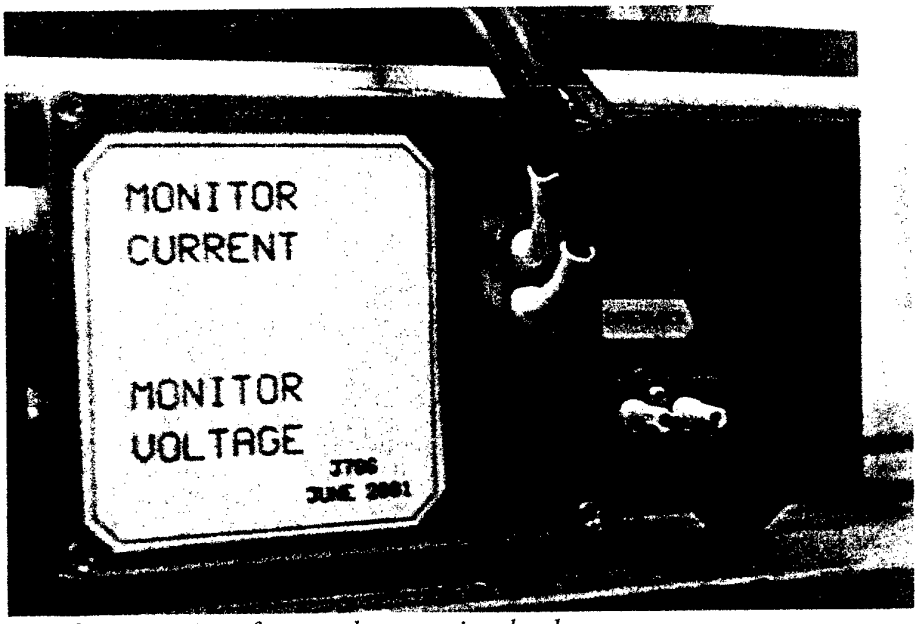
A 3. Sample holder



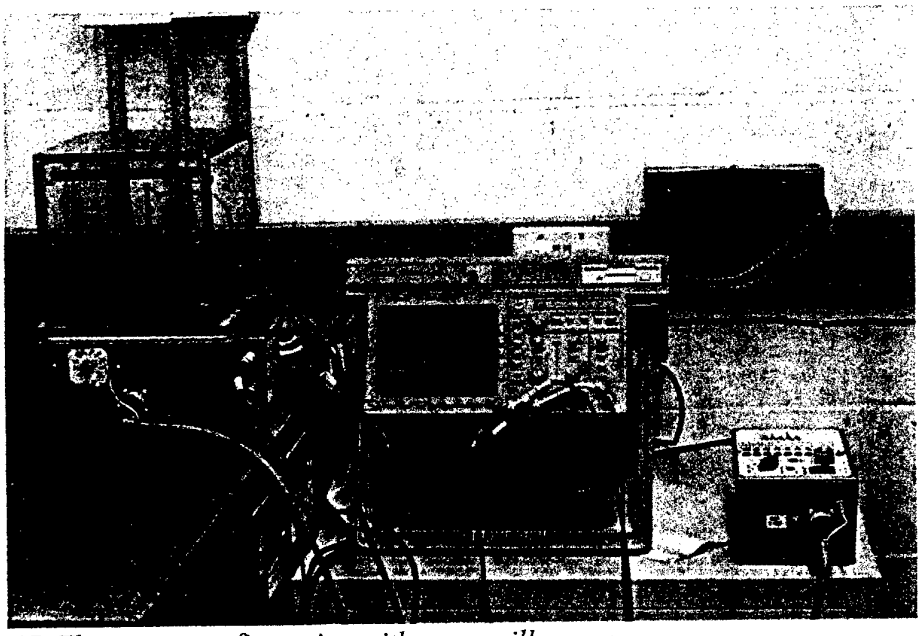
A 4. Sample holder in position for discharge



A5. EHT setting and EHT monitor output on the capacitor bank



A6. The output interface on the capacitor bank



A7. The set-up configuration with one oscilloscope